Photoproduction of Top Quarks in Peripheral Heavy Ion Collisions*

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Due to their large charges, relativistic heavy ions carry strong electromagnetic fields which may be treated as virtual photon fields. In a relativistic ion collider, these fields interact with target nuclei in the opposing beam, resulting in high luminosities for photonuclear interactions. Because of the large Lorentz boosts, high photon-nucleon center of mass energies are reached. Previous studies have considered photoproduction of charm and bottom quarks as well as nuclear breakup and vector meson production. These calculations all considered peripheral collisions, with impact parameter, b, greater than twice the nuclear radius R_A so that the two nuclei do not interact hadronically. Peripheral collisions will be studied experimentally at RHIC and the LHC, now under construction at CERN.

Here, we consider the production of top quarks via photon-gluon fusion, paralleling previous calculations of photoproduction in heavy ion collisions. In these collisions, a $t\bar{t}$ is produced in the reaction $\gamma(k) + A(P) \to t(p_1) + \bar{t}(p_2) + X$ where k is the four momentum of the photon emitted from the virtual photon field of the projectile nucleus, P is the four momentum of the interacting nucleon in ion A, and p_1 and p_2 are the four momenta of the produced t and $\bar{t}$ quarks. The photons are almost real. The slight virtuality is neglected. On the parton level, the photon-gluon fusion reaction is $\gamma(k) + g(x_2 P) \to t(p_1) + \bar{t}(p_2)$ where x_2 is the fraction of the target momentum carried by the gluon.

The photon flux is given by the Weizsäcker-Williams formulae. The flux is a function of the distance from the nucleus, r,

$$\frac{d^3N}{dkd^2r} = \frac{Z^2\alpha w^2}{\pi^2 kr^2}\left[K_1^2(w) + \frac{1}{\gamma^2}K_0^2(w)\right] \ , \quad (1)$$

where $w = kr/\gamma$ and $K_0(w)$ and $K_1(w)$ are modified Bessel functions. The photon flux is cut off at an energy determined by the size of the nucleus. In the rest frame of the target nucleus, the cutoff is boosted to $(2\gamma^2 - 1)\hbar c/R_A$, or 500 TeV for lead and 1400 TeV for calcium. The single photon cross section, $\gamma p \to t\bar{t}$, at the cutoff energy of calcium is a factor of 5.5 times larger than the cross section at the cutoff energy of lead. Thus the difference in the energy cutoffs of lead and calcium is significant.

The total photon flux striking the target nucleus is the integral of Eq. (1) over the transverse area of the target at all impact parameters subject to the constraint that the two nuclei do not interact hadronically.

Shadowing, the modification of the gluon distribution in nuclei, is included via a parameterization based on a fit to data. Shadowing is a small effect on the total cross sections since at $y = 0$ and $p_T = 0$, $\langle x_2 \rangle \approx 0.18$ for lead and 0.11 for calcium, close to the antishadowing region. In addition, at the large Q^2 required for top production, shadowing effects are further reduced by Q^2 evolution. The uncertainty in the large-Q^2 shadowing is significant since no data are available.

The total cross sections for $t\bar{t}$ pair production with lead and calcium beams are 496 pb and 94 pb. A one month run, 10^6 s, at design luminosity will produce 0.5 and 190 pairs respectively. The most significant factor in the rate difference comes from the luminosity, 10^3 times higher for calcium. A similar run with pA collisions will produce 15 and 88 pairs for lead and calcium beams respectively. The significant production rates and the relatively clean environment will allow for measurements of the top charge and mass. In addition, the gluon distribution of the nucleus can be measured at large Q^2.

*LBNL-45743; submitted to Phys. Lett. **B**.